COMPUTE kick-off meeting
2 March 2012

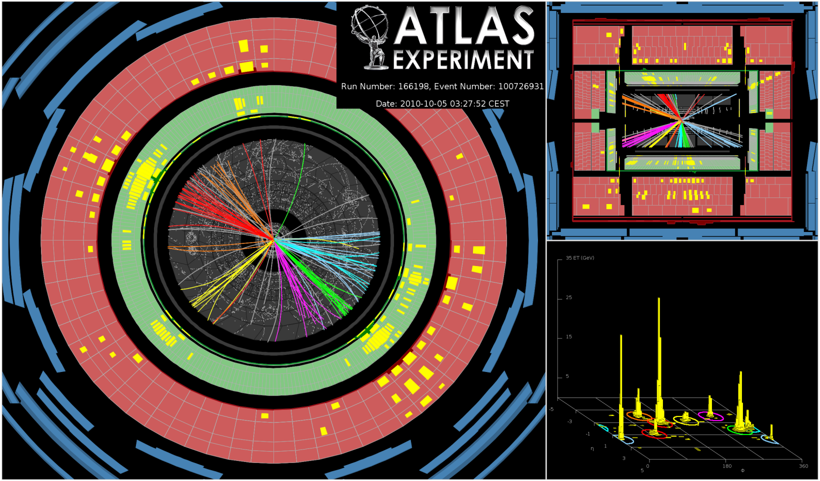
High Energy Collisions: On the Road to Monte Carlo

Torbjörn Sjöstrand

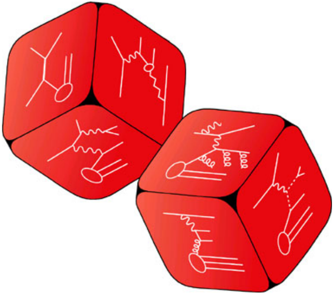
Theoretical High Energy Physics group

Department of Astronomy and Theoretical Physics
Lund University
Sölvegatan 14A, SE-223 62 Lund, Sweden

The LHC Challenge



Improve understanding of how physics works



Because Einstein was wrong:
God does throw dice!

Quantum mechanics:
amplitudes $\Longrightarrow$ probabilities

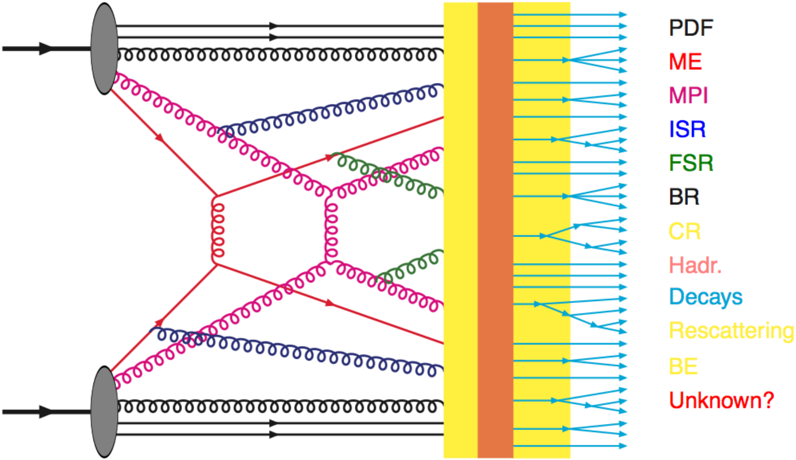
Anything that possibly can happen, will! (but more or less often)

Each event is unique!

Event Generators

- trace evolution of event structure
- combine theory with models
- describe averages and fluctuations
- describe special kinds of events

The complexity of events - 1

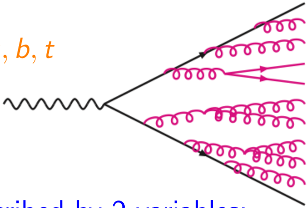


The Lund group has been leading in developing the *physics understanding* of several components, and *computational approaches* for even more.

Simplified example: FSR = Final State Radiation

Parton Shower = successive branchings by probabilistic procedure

Partons
quarks $q = d, u, s, c, b, t$
gluons g
photons γ
leptons $\ell = e, \mu, \tau$



Branchings
$q \to qg$, $q \to q\gamma$
$g \to gg$, $g \to q\overline{q}$
$\gamma \to q\overline{q}$, $\gamma \to \ell\overline{\ell}$
$\ell \to \ell\gamma$

Each branching described by 2 variables:

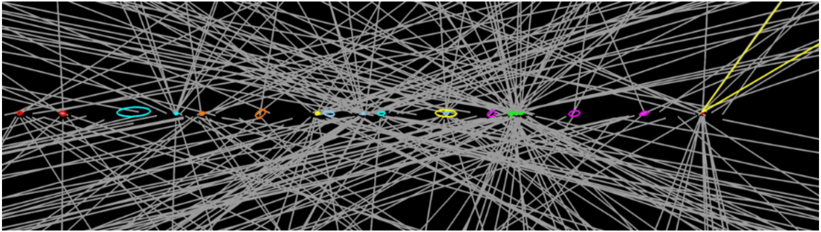
- $z \approx E_{\mathrm{daughter}}/E_{\mathrm{mother}}$, probabilities $P_{a\to bc}(z)$. Uncorrelated.
- $p_\perp$, transverse momentum kick of daughters w.r.t. mother. Heisenberg: $t \sim \hbar/p_\perp$; time ordering $\Rightarrow$ decreasing $p_\perp$.

$$\mathrm{d}\mathcal{P}_{a\to bc} = \frac{\mathrm{d}p_\perp}{p_\perp} P_{a\to bc}(z)\,\mathrm{d}z \, \exp\left(- \int_{p_\perp}^{p_{\perp\max}} \frac{\mathrm{d}p'_\perp}{p'_\perp} \int_{z_{\min}(p'_\perp)}^{z_{\max}(p'_\perp)} P_{a\to bc}(z')\,\mathrm{d}z' \right)$$

A parton can only branch once:
Sudakov form factor handled with *veto algorithm*.

The complexity of events - 2

- $\sim$ 10 different physics mechanisms in the evolution
- each with its set of physics rules
  - in part derived from theory, in some approximation
  - in part modelled, based on ideology or pragmatism
  - many model parameters must be tuned to data
- involves hundreds of “known” particles
- searches for hundreds of new models and new particles
- must allow for different preselection criteria



LHC generates $\sim$ 100 000 000 events/s, wheref $\sim$ 400 are saved.
Our generators can produce $\sim$ 10 events/s (process-dependent).

The computational challenge and usage

- The "evolution" of each event follows a unique path, involving a multitude of discrete and continuous choices, so no fine-grained parallelism.
- Each independent core can generate its stream of events, with analysis statistics combined for final results, so grid computing works fine.

In Lund:

- development/testing uses moderate computing resources
- physics studies could use more (at times)
- tuning can use much more ($\Rightarrow$ largely outsourced)

Internationally our generators are used:

- for detector design criteria (for LHC from 1990 onwards)
- to formulate event analysis strategies (also by theorists)
- to perform data corrections (+ detector simulation programs)

by thousands of physicists at hundreds of universities

Event generator people and projects

Jesper Roy Christiansen	student	PYTHIA
Gösta Gustafson	prof.em.	model development (DIPSY)
Leif Lönnblad	professor	ARIADNE, DIPSY, THEPEG
Stefan Prestel*	student	PYTHIA, ARIADNE
Malin Sjödahl	postdoc	basics of parton showers
Torbjörn Sjöstrand	professor	PYTHIA

- PYTHIA: general-purpose generator, goes back to 1978; $\sim$100k + 50k lines code + documentation (C++ $\leftarrow$ Fortran)
- ARIADNE: parton showers (ISR+FSR) in various approaches
- DIPSY: *pp*/*pA*/*AA* collisions in dipole approach
- THEPEG: generic framework for generators

MCnet

We are members of MCnet:
European collaboration of generator authors;
arranges schools; postdocs & students (if funded)

---

*poster on LHC@home/MCPLOTS tuning/validation effort

Other group activities

Johan Bijnens	professor	hadronic flavour physics
Stefan Lanz	postdoc	hadronic flavour physics
Roman Pasechnik	bitr.lekt.	within and beyond the Standard Model
Johan Rathsman	lektor	beyond the Standard Model
Johan Relefors	student	hadronic flavour physics
Thomas Rössler	student	beyond the Standard Model
Konrad Tywoniuk	postdoc	heavy-ion collisions

May involve some small amount of event-generator-style studies.

Algebraic calculation/manipulation more common here:

- MATHEMATICA, MAPLE: commercial – general-purpose.
- FORM: academic (GPL) – dedicated;
  can be used for matrix-element expressions involving
  more than 10^9 terms (at intermediate stages).

Currently no need for special computer hardware, but may change.

The future

- Improve precision of the “basic” processes
  - matching of “exact” perturbative calculations to approximate parton showers
  - modelling of soft, nonperturbative physics
- Try out new theoretical approaches to existing physics
  - parton showers based on alternative approximation schemes
  - alternative models for soft physics
- Implement new scenarios for physics beyond the “known” one
- Continue with analytic/algebraic studies

We are interested in COMPUTE to

- train students in computing techniques, e.g. basic parallel programming
- offer them more contacts within the faculty
- improve their employability